Water Treatment NOTES

Cornell Cooperative Extension, College of Human Ecology

Reverse Osmosis treatment of Drinking Water

BARBARA KNEEN. ANN LEMLEY AND LINDA WAGENET

Fact Sheet 4, December 1995 (Update November 2005)

Reverse osmosis (RO) systems can often improve the quality of water. The reverse osmosis water treatment method has been used extensively to convert brackish or seawater to drinking water, to clean up wastewater, and to recover dissolved salts from industrial processes. It is becoming more popular in the home market as homeowners are increasingly concerned about contaminants that affect their health, as well as about non-hazardous chemicals that affect the taste, odor, or color of their drinking water.

People considering the installation of a water treatment system to reduce toxic chemicals should first have their water tested to determine how much if any hazardous compounds are in the water. Public water supplies are routinely monitored and treated as required under the federal Safe Drinking Water Act and state regulations. Private water systems should be tested at the owner's initiative based on knowledge of land use and contamination incidents in the area.

Reducing contaminants through RO

Reverse osmosis treatment reduces the concentration of **dissolved solids,** including a variety of ions and metals and very fine suspended particles such as asbestos that may be found in water (see Table 1). An RO device may be installed following a water softener to reduce the concentration of sodium ions exchanged for hardness ions. RO also removes certain organic contaminants, some detergents, and specific pesticides.

Although RO membranes can remove virtually all microorganisms, it is currently recommended that only microbiologically safe (i.e., coliform negative) water be fed into RO systems.

Table 1. Reverse osmosis is an effective method of reducing the concentration of total dissolved solids (TDS) and many impurities found in water. Some of the compounds which RO systems are commonly used are listed below. These compounds may or may not be present in your water. The rate of reduction of each specific compound will depend on the RO membrane type and the system's operating conditions.

Ions and Metals

Arsenic (As)
Aluminum (Al)
Barium (Ba)
Bicarbonate (HCO3--)
Cadmium (Cd)
Calcium (Ca)
Carbonate (CO3--)
Chloride (Cl)
Chromium (Cr)
Copper (Cu)
Fluoride (F)
Iron (Fe)
Lead (Pb)
Magnesium (Mg)
Manganese (Mn)
Mercury (Hg)
Nitrate / Nitrite (NO_3^-/ NO_2-)
Potassium (K)
Radium (Ra)
Selenium (Se)
Silver
Sodium (Na)
Sulfate (SO4--)
Zinc (Zn)

Organic Chemicals

Benzene
Carbon tetrachloride
Dichlorobenzene
MtBE
Toluene
Trichloroethylene
Total Trihalomethanes (THMs)

Particles

Asbestos
Protozoan cysts

Pesticides

1,2,4-trichlorobenzene
2,4-D
Atrazine
Endrin
Heptachlor
Lindane
Pentachlorophenol

Some RO systems, however, may be used for removing waterborne protozoan cysts (such as *Cryptosporidium and Giardia)* found in surface drinking water supplies. Only treatment systems certified for cyst reduction by NSF, International (a nonprofit agency that tests health-related products) should be used for this purpose. (See the section "Choosing an RO System.")

Reverse osmosis will not remove all contaminants from water. Dissolved gases such as oxygen and carbon dioxide pass through RO membranes into the treated water. Unfortunately, hydrogen sulfide gas, with its notorious odor of rotten eggs, also passes through the RO membrane. RO in general is not a very effective treatment for trihalomethanes (THMs), some pesticides, solvents, and other volatile organic chemicals (VOCs).However, RO systems can be certified by NSF for VOCs, THMs, and several pesticides and solvents if the contamination is not too high. If the water source is severely polluted or untreatable, a public water supply or a reliable private water source must be used.

The reverse osmosis process

In the reverse osmosis process a cellophane-like membrane separates purified water from contaminated water. An understanding of **osmosis** is needed before further describing RO. Osmosis occurs when two solutions containing different quantities of dissolved chemicals are separated by a semi permeable membrane (allowing only some compounds to pass through). **Osmotic pressure** of the dissolved chemical causes pure water to pass through the membrane from the dilute to the more concentrated solution (Figure 1) There is a natural tendency for chemicals to reach equal concentrations on both sides of the membrane.

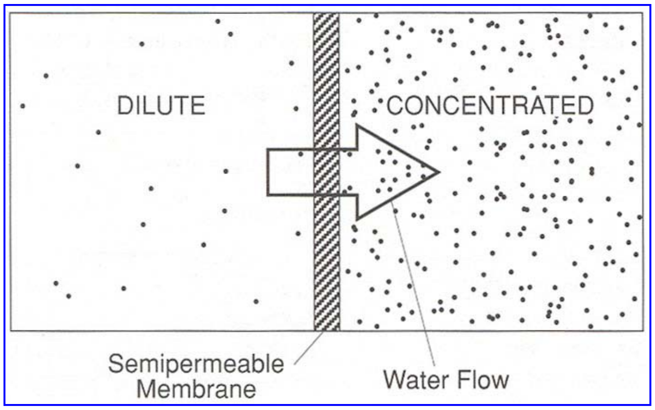


Figure 1. *In osmosis, water across the membrane from the dilute to the concentrated solution*

In reverse osmosis, water pressure applied to the concentrated side forces the process of osmosis into reverse. Under enough pressure, pure water is "squeezed" through the membrane from the concentrated to the dilute side (Figure 2). Salts dissolved in water as charged ions are repelled by the RO membrane. Treated water is collected in a storage container. The rejected impurities on the concentrated side of the membrane are washed away in a stream of wastewater, not accumulated as on a traditional filter.

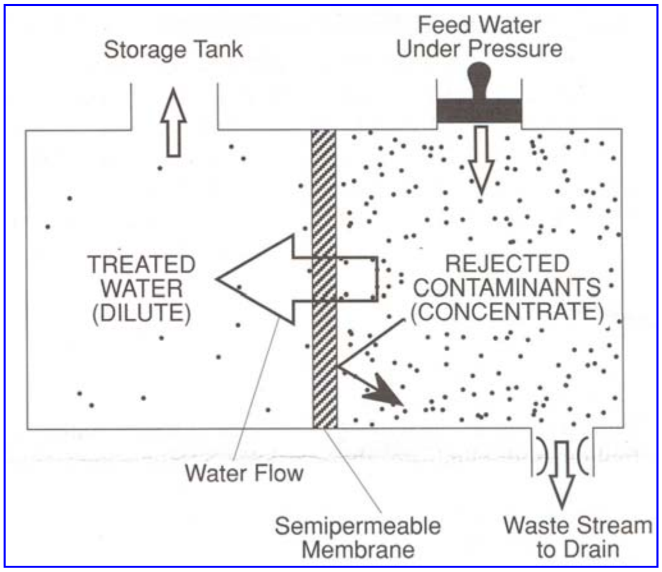


Figure 2. *The reverse osmosis, pressure is applied to the concentrated solution reversing the natural direction of flow, forcing water across the membrane from the concentrated solution into the more dilute solution*

The RO membrane also functions as an **ultrafiltration** device, screening out particles, including microorganisms that are physically too large to pass through the membrane's pores. RO membranes can remove compounds in the 0.0001 to 0.1 micron size range (thousands of times smaller than a human hair).

Design of an RO system

Although the reverse osmosis process is simple, a complete water treatment system is often complex, depending on the quality of the incoming water before treatment and the consumer's needs. Most home RO systems are point-of-use (POU) units placed beneath the kitchen sink to treat water used for cooking and drinking. Point-of-entry (POE) systems that treat all the water entering the household are more expensive to purchase and operate than POU systems.

A typical home reverse osmosis system consists of pretreatment and post-treatment filters as well as the RO membrane, flow regulator, storage container for the treated water, and dispensing faucet (Figure 3). The pressure for RO is usually supplied by the feed line pressure of the water system in the home, but a booster pump may be needed to produce an adequate volume of treated water. A sediment pre-filter is essential for removing relatively large sand grains and silt that may tear or clog the RO membrane or clog a pump or flow regulator. Water softeners are used in advance of the RO system when household water is excessively hard. If the water is chlorinated or contains other oxidizing chemicals such as bromine, an activated carbon pre-filter is needed to protect membranes sensitive to these chemicals.

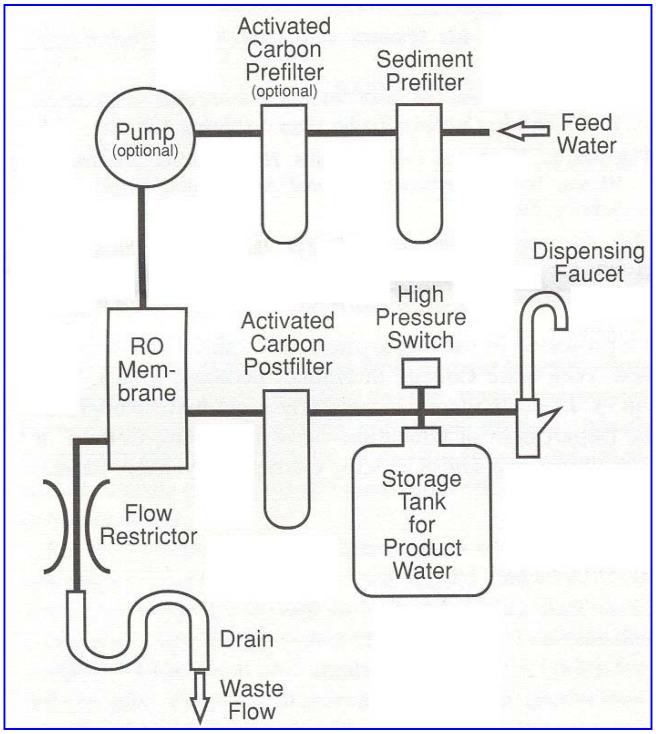


Figure 3. *A schematic of a typical RO system*

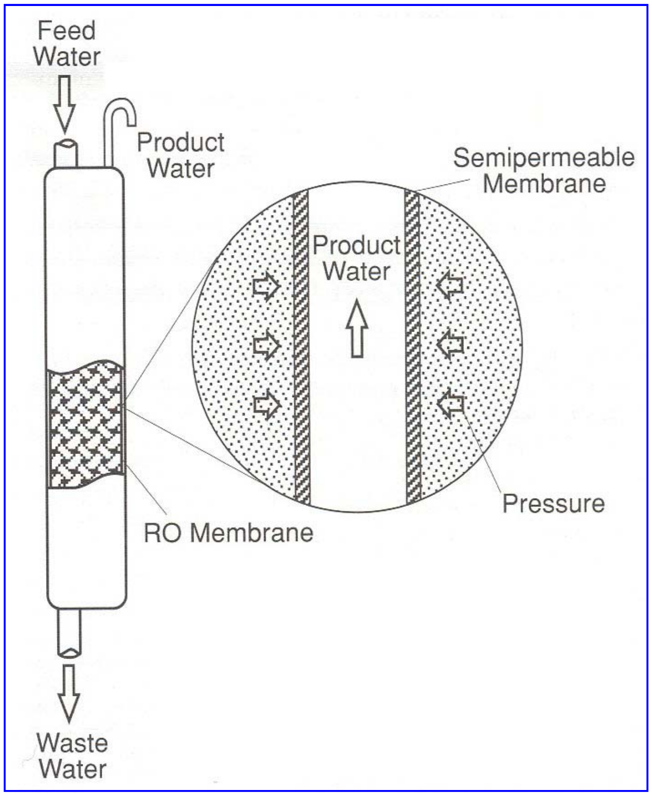
To remove certain pesticides and organic solvents, an activated carbon (AC) post-treatment must be included in the system. A standard AC filter positioned after the storage tank removes compounds that cause unpleasant taste and odors, including those from the tank or plastic tubing, just before water is dispensed. To remove high levels of organic chemicals such as trihalomethanes, volatile organic chemicals, and chloramines, an additional prolonged contact carbon filter (PCCF) is placed between the RO membrane and the storage tank. Combining an activated carbon filter with RO expands the range of chemicals the system can remove. Furthermore, AC treatment is improved because RO removes compounds that adversely affect AC adsorption. For more information about activated carbon, see Fact Sheet 3 in this *Water Treatment Notes* series.

The storage tank, tubing, and dispensing faucet should be made of plastic, stainless steel, or other nontoxic materials. The low pH and mineral content of RO-treated water may corrode copper pipes and allow lead to leach into the drinking water from brass components.

RO membrane materials

The most common RO membrane materials are polyamide thin film composites (TFC) or cellulosic types (cellulose acetate [CA], cellulose triacetate [CTA], or blends). Very thin membranes are made from these synthetic fibers. Membrane material can be spiral-wound around a tube, or hollow fibers can be bundled together, providing a tremendous surface area for water treatment inside a compact cylindrical element (Figure 4). Hollow fiber membranes have greater surface area (and therefore greater capacity) but are more easily clogged than the spiral-wound membranes commonly used in home RO systems.

Figure 4. *A typical osmosis device Adapted from Lykins, B. W., Jr., Clark, R. M., Goodrich, J.A., 54,*



Point-of-Use/Point-of-Entry for Drinking Water Treatment, *Lewis publishers, an imprint of CRC Press Boca Raton, Florida, 1992. With permission*

The flux, or capacity, of the RO membrane indicates how much treated water it can produce per day. Typically, RO membranes for home systems are rated in the range of 24 to 100 gallons per day. Thus, under standard operating conditions it could take from two to six hours to fill a two and-a-half-gallon storage tank. CA/CTA membranes have adequate capacity for most households, but TFC membranes should be used if large volumes of treated water are needed.

RO membranes are rated for their ability to reject compounds from the contaminated water. A rejection rate (% rejection) is calculated for each specific ion or contaminant as well as for reduction of total dissolved solids (TDS). It is important that consumers know their specific requirements for water quality when buying a system. For example, high rejection rates are essential when high nitrates or lead concentrations in the water must be brought below the EPA maximum contaminant or action levels.

Although thin film composite membranes are initially more expensive, they have superior strength and durability, as well as higher TDS rejection rates (>95%), than cellulosic membranes (88 - 94%). TFC membranes are more resistant to microbial attack, stand up better to high pH (greater than 9) and are better able to handle higher levels of total dissolved solids (1, 500 -2,000 ppm) than cellulosic (CA/CTA) membranes. The advantages of cellulosic membranes are their lower cost and ability to tolerate chlorine, which curtails the growth of microorganisms in the system. Thin film composites deteriorate in chlorinated water but perform well with an activated carbon prefilter to remove chlorine.

Membranes made of sulfonated polysulfone (SPS) are chlorine tolerant (like CTA) and can withstand higher pH levels (like TFC), but they do not match the low costs of CTA or the performance of TFC. SPS membranes are best used in RO systems when the feed water is soft and high in pH or when high nitrate levels are a primary concern.

Nanofiltration membranes (also referred to as loose RO or softening membranes) have much higher flow rates than other membranes. They tend to reject negatively charged ions such as sulfates very well but do not perform well in removing total dissolved solids.

Efficiency of ROsystems

The performance of an RO system depends on membrane type, flow control, feed water quality (e.g., turbidity, TDS, and pH), temperature, and pressure. The standard at which manufacturers rate RO system performance is 77 °F, 60 pounds per square inch (psi), and TDS at 500 parts per million (ppm).Only part of the water that flows into an RO system comes out as treated water. Part of the water fed into the system is used to wash away the rejected compounds and goes down the drain as waste.

The recovery rate, or efficiency, of the system is calculated by dividing the volume of treated water produced by the volume of water fed into the system:

$$\% \text{ Recovery} = \frac{\text{Volume of Treated Water Produced}}{\text{Volume of Feed Water Used}}$$

If not properly designed, RO systems can use large quantities of water to produce relatively little treated water. Most home RO systems are designed for 20 to 30% recovery (i.e., 2-3 gallons of treated water are produced for every 10 gallons put into the system). Home RO systems can operate at higher recovery rates, but doing so may shorten membrane life.

The flow regulator on the reject stream must be properly adjusted. If the flow is slow, the recovery rate is high, but RO membranes are easily fouled if concentrated impurities are not washed away quickly enough. If the flow is too fast, the recovery rate is low and too much water goes down the drain.

Overall water quality affects the efficiency of an RO system and its ability to remove specific contaminants. The higher the TDS, the lower the recovery rate of treated water.

The amount of treated water produced decreases 1 to 2 percent for every degree below the standard temperature of 77 °F. An RO system supplied with well water at a temperature of 60 °F produces only three-quarters of the volume it would produce at 77 °F.

For an RO system to function properly, there must be enough **water pressure.** Although most home RO systems are rated at 60 pounds per square inch, the incoming **feed fine pressure** of many private water systems is less than 40 psi. The RO system must work against **back pressure** created in the storage tank as it **fills** with water and compresses the air in the tank. The RO device must also overcome **osmotic pressure,** the bonding between water molecules and the dissolved impurities; the higher the TDS level, the greater the osmotic pressure. The **net water pressure** at the RO membrane can be calculated by subtracting back pressure and osmotic pressure from the feed line pressure. If the net water pressure at the membrane is lower than 15 psi, treated water production is less efficient and contaminant rejection rates are lower.

Auxiliary pumps can be added to the treatment system to boost pressure and improve the quality and quantity of water produced. High-quality RO systems have valves that shut off the flow whenever storage tank pressure reaches two-thirds of the feed pressure; at that point, low net water pressure can result in low rejection rates.

In some systems, once the storage tank is **filled,** surplus treated water is discarded; water loss from such units is frequently excessive. A system that automatically shuts off when the pressure on the tank reaches a given level saves water.

Maintenance of an RO system

An RO system must be well maintained to ensure reliable performance. Clogged RO membranes, filters, or flow controls will decrease water flow and the system's performance. If fouling is detected in the early stages the membrane can often be cleaned and regenerated. The cleaning procedure varies depending on the type of membrane and fouling. Completely clogged or torn RO membranes must be replaced. In addition, pre- or post-filters must be replaced once a year or more often, depending on the volume of water fed through the system and the quality of the feed water.

Damage to RO membranes cannot be seen easily. The treated water must be analyzed periodically to determine whether the membrane is intact and doing its job. Many systems now have a built-in continuous monitor that indicates a high TDS level, a sign that the system is not operating properly. It may also be necessary to test regularly for specific health-related contaminants such as nitrates or lead.

Microorganisms, dead or alive, can clog RO membranes. To prevent bio-fouling, RO units must be disinfected periodically with chlorine or other biocides provided by the manufacturer. Continuous chlorination can be used with cellulose membranes to protect the system from biofouling and eliminate the particle-trapping slime that worsens other forms of fouling such as scaling.

Chlorine and other oxidizing disinfectants are harmful to thin film composite membranes. If the feed water is chlorinated, an activated carbon unit must be in place to remove the oxidizing chemicals before they reach the TFC membrane. Activated carbon (AC) prefilters should not be used on nonchlorinated water supplies because they provide a place for microorganisms to multiply and lead to increased bio-fouling of the RO membrane surface. It is important to replace AC filters periodically following the manufacturer's instructions, especially after an extended shutdown period during which microorganisms can flourish.

Choosing an RO system

Homeowners who are thinking about buying a reverse osmosis system should determine their initial water quality and their goals in adding a water treatment system. The answers to the following questions will help homeowners choose an RO system wisely.

1. What is the quality of your drinking water?

Have your water tested by a certified laboratory to determine which contaminants, if any, are present and which water treatment system is best suited to your situation. .

If reverse osmosis is an appropriate treatment, other test results (such as those for coliform bacteria, TDS, and pH) will help determine which pretreatment or post-treatment is needed and will influence the choice of membrane

2. What type and concentration of contaminants do you expect the RO system to remove?

When considering the purchase of RO equipment, ask what the contaminant passage and rejection rates are for that system under typical home water conditions. Ask for the rejection rates for each specific health-related contaminant of concern to you and your family as- well as for TDS rejection rates.

RO systems can be certified for reduction of specific contaminants if they pass performance tests conducted by NSF, International. Look for the NSF mark, which assures that the manufacturer's contaminant reduction claims are true and that the materials used comply with NSF standards. You can also find the concentration reductions that a certified device can perform for specific contaminants on the website www.nsf.org.

3. How much treated water is needed in the home?

The volume of treated water that can be produced (in gallons per day) is determined by the water pressure and the size of the holding tank, as well as the membrane capacity. If the water pressure coming into your home is low or TDS levels are high, you may need a booster pump. Individual home booster pumps are not allowed at the service connection to a public water supply main.

4. What are the installation, operation, and maintenance costs of an RO system?

The price of buying and installing an RO system ranges from about $200 to over $2,000, depending on the features of the system and the water quality problems it must handle. The costs of maintaining an RO system include monitoring the product water, periodically replacing membranes and filters (pre- and post-treatment), and disinfecting and servicing the system. Renting an RO system instead of buying is an option.

Ask about the recovery rates of various RO systems and estimate how much wastewater will be generated. Consider the effect on your water bill; look for a water-saving shutoff valve on the storage tank. An on-site septic system may not be able handle the extra wastewater load from a water treatment system. Discharge of reject water from an RO system to the ground surface should be approved by the local health department.

Other treatment methods may be more cost effective than reverse osmosis for removing the contaminant(s) of concern to you. Drinking bottled water may be a less expensive alternative than treatment if the amount of water used is small.

To calculate the cost of a gallon of RO-treated water, divide the monthly cost of the treatment system by 30, then divide by the number of gallons of RO-treated water used per day. In some cases, installing an RO system may be the best choice.

Summary of reverse osmosis

RO removes many inorganic impurities from drinking water. Its effectiveness depends not only on the type of membrane but on feed water, quality, temperature, pressure, and flow control, as well as the type and concentration of specific contaminants to be removed.

- Look for the NSF certification mark on the RO system to be sure that the manufacturer's claims for reducing contamination are true.
- RO is not effective for removing dissolved gases, some pesticides and solvents, hydrogen sulfide gas, THMS, VOCs, and chloramines.
- A typical RO system consists of a sediment filter, pump, reverse osmosis membrane, flow regulator, storage tank, final activated carbon filter (for taste and odors), and dispensing faucet. An AC prefilter is sometimes needed for dechlorination.
- RO is commonly used to treat only the water used for drinking and cooking at the point of use rather than at the point of entry for all household use.
- RO membrane types vary in their ability to reject contaminants and differ in capacity (the volume of treated water produced per day).
- Water pressure is an important factor in determining the RO system's rejection rate, capacity, and recovery rate (amount of treated water produced per amount of feed water used).
- Maintenance of an RO system is essential for reliable performance. High levels of TDS and microorganisms in the system are commonly the cause of fouled membranes.
- The treated water should be monitored for TDS and the level of any specific contaminants that may affect your family's health.

References

Ethen, T. A. 6 Pieces of the Home RO Puzzle. *Water Technology,* Aug. 1995.

Faulkner, M. The Basics of RO Components. *Water Technology,* Aug. 1995.

Lykins, B. W. Jr., R. M. Clark, and J. A. Goodrich. *Point-of-Use / Point-of-Entry for drinking Water Treatment.* Chelsea, Mich.: Lewis, 1992.

Montemarano, J., and R. Slovak. Factors That Affect RO Performance. *Water Technology,* Aug. 1990.

Northrup, L. 5 RO Installation Tips. *Water Technology,* Aug.1993.

NSF Standard Number 58. Ann Arbor, Mich., 1994.

Paul, D. Disinfect RO Systems with Care. *Water Technology,* Sept.1994.

Rozelle, L. T. Reverse Osmosis Process, Theory and Membranes, Parts I and II. *Culligan Technology 1* (Spring 1983).

Wagenet, L., K. Mancl, and M. Saflus. *Home Water Treatment.* Ithaca, N.Y.: Northeast Regional Agricultural Engineering Service, 1995.

The authors

Barbara Kneen and Linda Wagenet are former Extension Associates, and Ann Lemley is Professor and Chair in the Department of Textiles and Apparel, College of Human Ecology, Cornell University,

FACT SHEET 4 ,DECEMBER, 1995
(Updated November 2005)

This publication is issued to further Cooperative Extension work mandated by acts of Congress of May 8 and June 30, 1914. It was produced with the cooperation of the U.S. Department of Agriculture; Cornell Cooperative Extension; and the College of Agriculture and Life Sciences, the College of Human Ecology, and the College of Veterinary Medicine at Cornell University. Cornell Cooperative Extension provides equal program and employment opportunities. Helene R. Dillard, Director

Cornell University
Cooperative Extension